

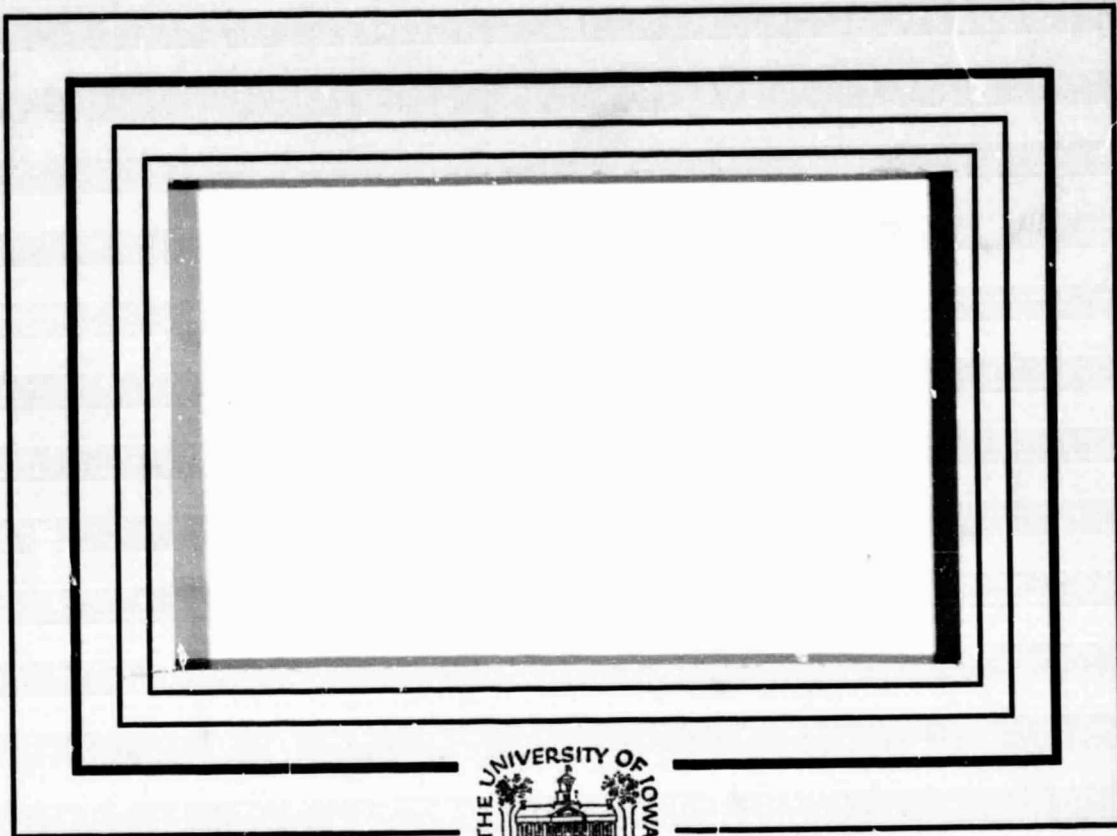
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(NASA-CR-175127) [REDUCTION AND ANALYSIS OF
DATA FROM THE PLASMA WAVE INSTRUMENTS ON THE
IMP-6 AND IMP-8 SPACECRAFT] Final Report
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Final Report for NASA

Contract NAS5-26125

by

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I. INTRODUCTION

This report describes the activities supported by NASA Contract NAS5-26125 for the period from April 1, 1980 to March 31, 1982. This contract was for the reduction and analysis of data from the plasma wave instruments on the IMP 6 and IMP 8 spacecraft. The primary data reduction effort during the reporting period was to process summary plots of the IMP 8 plasma wave data and to submit these data to the National Space Science Data Center. A summary of all data processed and submitted to NSSDC is given in Section II.

The scientific analyses during the reporting period were reduced compared to previous years because of the competing requirement to conduct the analysis of data from the Voyager 1 and Voyager 2 flybys of Jupiter and Saturn, which occurred during this same period. Much of the scientific activity consisted of supporting research by other groups using the IMP 8 plasma wave data. Among the main accomplishments include a study of broadband electrostatic in the magnetic tail by Nishida et al. [1983], and a study of ion waves associated with solar wind beam-plasma interactions by Rodriguez [1981]. Other papers involving IMP 6 and IMP 8 published during the reporting period are listed in Section III.

In addition to the published papers, a number of other research activities were conducted that either did not lead to publications, or are still under way. One graduate student, Mr. Dennis Gallagher, was

supported by this contract during most of the reporting period. He was mainly responsible for the IMP 8 data processing. In addition to his data processing duties, Mr. Gallagher also spent considerable time working on broadband electrostatic noise in the magnetotail and magnetosheath. Although he initially was using IMP 8 data for this study, his research eventually led to his Ph.D. thesis and a publication using only ISEE data, because for his purpose the ISEE data was superior to the IMP 8 data. Thus, although this contract supported his initial efforts, no publication is listed, because the final publication only used data from ISEE. A study of broadband electrostatic noise in the magnetotail was also started with Tony Lui of Johns Hopkins Applied Physics Laboratory. This study is still under way and will be eventually published.

II. SUMMARY OF DATA PROCESSED

During this contract period, April 1, 1980 to March 31, 1982, we generated on microfilm 24-hour electric and magnetic fields plots of IMP 8 data covering the time period July 29, 1979 through December 8, 1981. Microfilm copies of all of these plots were submitted to the National Space Science Data Center which now has microfilm copies of all IMP 8 24-hour electric and magnetic field plots from October 31, 1973 through December 8, 1981.

III. PUBLICATIONS

1. Volume Emissivity of Type III Radio Bursts
R. L. TOKAR and D. A. GURNETT
J. Geophys. Res., 85, 2353, 1980.
2. Plasma Oscillations and the Emissivity of Type III Radio Bursts
D. A. GURNETT, R. R. ANDERSON and R. L. TOKAR
Radio Physics of the Sun, ed. by M. Kundu, Reidel, Dordrecht.
p. 369, 1980.
3. A Test of Two Theories for the Low Frequency Cutoffs of Nonthermal Continuum Radiation
R. R. SHAW and D. A. GURNETT
J. Geophys. Res., 85, 4571, 1980.
4. Interplanetary Particles and Fields, November 22 to December 6, 1977: Helios, Voyager, and Imp Observations Between 0.6 and 1.6 AU
L. BURLAGA, R. LEPPING, R. WEVER, T. ARMSTRONG, C. GOODRICH, J. SULLIVAN, D. GURNETT, P. KELLOGG, E. KEPPLER, F. MARIANI, F. NEUBAUER, H. ROSENBAUER, and R. SCHWENN
J. Geophys. Res., 85, 2227, 1980.
5. Ion Waves Associated With Solar Wind Beam-Plasma Interactions
PAUL RODRIGUEZ
J. Geophys. Res., 86, 1279, 1981.
6. Broadband Electrostatic Noise in the Magnetotail: Its Relation to Signatures of Reconnection
A. NISHIDA, K. A. ANDERSON, R. R. ANDERSON, S. J. BAME and E. W. HONES, JR.
J. Geophys. Res., in press, 1983.

Broadband Electrostatic Noise in the Magnetotail:

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Abstract

Intense broadband electrostatic noise is often observed in the magnetotail when the fast tailward flow and the southward polarity of the magnetic field signify the progress of reconnection. We compare features of the noise with simultaneous observations of the magnetic field, plasma and energetic electrons. Spectral characteristics of the noise and the results of this comparison both suggest that in its high frequency ($f > f_g^-$) part at least the noise does not belong to normal modes of plasma waves but represents either quasi-thermal noise in the non-Maxwellian plasma or artificial noise generated by spacecraft interaction with the medium.

Introduction

Plasma wave detectors on board earth-orbiting spacecraft have frequently recorded bursts of electrostatic noise whose spectrum extends over a very broad range. The noise, called "broadband electrostatic noise" by Gurnett and colleagues, has a lower cutoff near the local lower hybrid frequency. On the high frequency side the spectrum tends to decline at the local electron gyrofrequency f_g^- but does not terminate there. Often the spectrum extends to the local electron plasma frequency f_p^- and sometimes beyond. The noise appears as bursts which show little dispersion over the frequency range of 0.1~10kHz, and there is little indication of the banded structure that would be expected if the noise belonged to the cyclotron harmonic band. The broadband electrostatic noise has been observed at the bow shock and the magnetosheath (Rodriguez et al., 1975; Anderson et al., 1982), in the magnetotail (Gurnett et al., 1976), along field-lines that are connected to the auroral zone (Gurnett and Frank, 1977), in the polar cusp (Scarf et al., 1972; Gurnett and Frank, 1978), and at the magnetopause (Gurnett et al., 1979). Essentially identical wave phenomena have been detected also in the Jovian magnetosphere (Barbosa et al., 1981).

The nature of the broadband electrostatic noise is not yet understood. Although the electrostatic ion-cyclotron instability and the lower-hybrid-drift instability have been suggested as possible generation mechanisms (Gurnett et al., 1979; and papers cited therein), there is a wide gap between the frequency of the unstable waves and the high-frequency end of the observed spectrum. It is even questionable

if the noise can be attributed to one of the normal modes of plasma waves because the duration of the burst can be as short as < 8 ms. Hence Anderson et al. (1982) have been led to suggest that the noise (which they called "spikes") has the characteristics of small scale plasma potential irregularities convecting past the antenna.

This brief report analyzes the enhancements of the broadband electrostatic noise that occurred in association with the signatures of the formation of the magnetic neutral line in the magnetotail. These signatures comprise the southward polarity of the magnetic field and the tailward flow of plasma having velocities greater than about 300 km/s (Nishida et al., 1981; Hayakawa et al., 1982). We compare spectrum and intensity of the wave with observations of the magnetic field, plasma, and energetic electrons on October 20 and 21, 1972. Several well-defined signatures of the neutral line formation were recorded on these days when Imp 6 was at the radial distance of about $30R_e$.

Imp 6 was a spin stabilized satellite with spin axis perpendicular to the ecliptic plane and spin period of 11.1 s. Plasma waves were measured by the University of Iowa using 92.5 m tip-to-tip antennas and a single turn loop antenna. Magnetic field was measured by GSFC fluxgate magnetometer. Velocity and density of plasma were obtained from ion measurements by LASL hemispherical plate electrostatic analyzer covering the 13 eV to 28.8 keV range. Energetic electron measurements by the University of California, Berkeley, were performed by two semiconductor detector telescopes and two Geiger Müller detectors.

Analysis

Figure 1 displays data of the plasma flow velocity v and the inclination θ of the magnetic field in October 20 to 21, 1972. Velocity vectors are shown as projections to the solar ecliptic plane and the upward vector in the figure corresponds to the sunward flow. Field inclinations refer to the solar magnetospheric coordinates and positive θ means the northward polarity. Thick arrows in the velocity panel indicate onsets of tailward flows which lasted for 5~20 min. These tailward flows accompany southward polarity of the magnetic field and hence can be interpreted to be the product of reconnection that is operating on the earthward side of the spacecraft.

Figure 2 shows 16-channel spectrum analyzer data for the same period. The spectrum covers the frequency range of 178 kHz to 0.036 kHz, and left and right panels show electric and magnetic field spectra, respectively. For each channel vertical bars represent average field strengths and dots are the peak field strengths over intervals of 81.8 s. The spacing between baselines of the neighbouring channels corresponds to a range of 100 dB.

The arrows in the spectrum data are drawn at the times of onsets of fast tailward flows. It is evident that each of these arrows roughly coincides with intensifications of waves having a very broad bandwidth. Since the ratio of the electric field to the magnetic field is large the waves are essentially electrostatic. For the electric field the band extends from the lowest frequency channel (0.036 kHz) to 5~10 kHz. For the magnetic field the upper frequency limit is slightly lower (a few

kHz). These upper cutoff frequencies are higher than the local electron gyrofrequency f_g^- which is indicated by solid curves superposed on the spectral data. The plasma frequency ($f_p^- = \omega_p^- / 2\pi$) during the period was in the 1-5 kHz range except when the spacecraft briefly exited the plasma sheet and entered the lobe due probably to the plasma-sheet thinning. The upper cutoff frequency of the electric-field noise is in the neighbourhood of f_p^- . Continuous enhancement of the electric field at higher frequencies (10.0 kHz and 16.5 kHz) corresponds to the non-thermal continuum reported by Gurnett (1975). Sometimes the broadband noise appears even in the 10.0 kHz channel superposed on the continuum.

High resolution frequency-time spectrograms produced from wide band data are shown in Figure 3. In samples (a) through (c) the broadband electrostatic noise is recorded as burst-like intensifications with continuous spectra. In most cases the power is higher at lower frequencies as exemplified in (a) and (b), but relatively infrequently the peak is at several kHz as seen in the middle part of (c). There is no clear indication of the intensity modulation with the spin period. Occasionally banded features also appear in the spectrogram as illustrated in (d) but they do not interact with the bursts.

If this broadband electrostatic noise represents the Doppler shifted ion sound wave, ion cyclotron wave or lower hybrid drift wave, the extent of the Doppler shift has to be as large as several kHz. However, since electron density is $10^{-1} \sim 10^{-2} / \text{cm}^3$ and electron temperature is 1-2 keV at the times of the intense noise, the Debye length is about 10^5 cm and the Doppler shift can only be about 0.5 kHz.

The above interpretation is therefore untenable. In the frequency range above f_g there exists electrostatic electron cyclotron mode, but the observed spectrum does not show the banded feature characteristic to this mode.

The arrows in Figure 2 agree also with intensifications in high frequency channels (178 and 100 kHz). The high frequency wave represents auroral kilometric radiation which has been known to be associated with ground signatures of substorms (Gurnett, 1974). The activation of the auroral kilometric radiation at times of fast tailward flows is a consistent feature, since reconnection in the near-earth region tends to be associated with substorm signatures detectable on the ground (e.g., Hones and Schindler, 1979; Nishida et al., 1981).

In an attempt to find out a clue on the generation mechanism of the broadband electrostatic noise we compare in Figures 4 and 5 the intensity of the noise with the flux of energetic electrons and the density of keV range plasma. The noise intensity is represented by the power recorded in the 1 kHz channel. Intervals of particularly high noise strength are shaded to guide the eyes. Arrows indicating the beginning of fast tailward flows are reproduced above the middle panel containing the electron density plot. In these expanded diagrams the increase of the noise strength at the onset of the first tailward flow is quite clear. The peak intensity, however, tends to be recorded a few minutes or a few tens of minutes later when the plasma density has been reduced due probably to the thinning of the plasma sheet. There seems to be a rough correspondence between the maximum in the noise level and the minimum in the plasma density. These appear to be

coincident also with spike-like enhancements in the flux of energetic electrons, although the available time resolution does not allow us to make a very definitive statement.

Figure 6 presents a similar comparison in a slightly different format. Onset time of the fast tailward flow and the interval of the plasma sheet thinning are indicated in top panel which contains the plot of the energetic electron flux. There is a burst of energetic electrons coincident with the onset of the fast tailward flow, and the noise strength starts to increase at that time. The noise strengths peak during the plasma sheet thinning when the energetic electron flux rises sporadically. It drops appreciably after the peak but still registers elevated values in the 1845~1915UT interval while the plasma flow has turned earthward but is fast ($\gtrsim 600$ km/s). The bottom panel shows average anisotropy of energetic electrons during the intervals A, B and C indicated in the top panel. This average anisotropy is calculated by normalizing the fluxes in 16 sectors obtained in a scan period of 20.5s by assigning 1.0 to the maximum flux and then averaging the normalized flux in each sector for each interval. Outer radius of each circle corresponds to 1.0 and the letter S denotes the direction of the sun which was roughly parallel to the magnetic field direction. The average anisotropy is suggestive of neither dumbbell nor cigar-like distribution, but since the scan period is much longer than the duration of the noise burst the essential information may have been lost.

Discussion

Broadband electrostatic noise in the magnetotail was reported first by Gurnett et al (1976). (Electric field oscillations detected at 1.3 kHz and 270-810 Hz channels before the spacecraft entry into the plasma sheet by Scarf et al (1974) may also have involved the noise of this type.) The events analyzed here had many of the characteristics noted by Gurnett et al., namely the occurrence in the form of many discrete bursts, the broadness of the spectrum extending from ~ 0.1 to several kHz, the association with fast plasma flows, and the association with increases in intensities of the auroral kilometric radiation. However, we could not clearly recognize the V-shaped frequency-time variation nor the intensity modulation with the spin period recognized by Gurnett et al. We could not generalize their observation (at a "fireball" event) that the maximum electric field intensities occur essentially coincident with the northward-to-southward turning of the magnetic field and a corresponding earthward-to-tailward switch in the flow direction to other events which are accompanied by essentially similar variations in field and flow.

The case studies of Gurnett et al. and of this paper might have given one an impression that the broadband electrostatic noise occurs only in the disturbed magnetosphere involving fast flows in the plasma sheet, rapid and frequent boundary motions of the plasma sheet, and high intensities of the auroral kilometric radiation. To make up for such an impression we present in Figure 7 examples of the broadband electrostatic noise which were observed in an interval of low flow speed, relatively constant density, low levels of the AKR and the AE

index. The cases in question are the noise bursts observed at ~ 0450 and ~ 0535 . In these cases the extension of the spectrum can be noted even at the highest frequency channel (178 kHz). The absence of AKR and the continuum radiation allowed the broadband electrostatic noise to stand out to very high frequencies. It may be significant that these bursts are accompanied by quite small but clear changes in velocity, density and temperature.

Our motivation for examining the plasma wave observations associated with the reconnection signatures in the magnetotail was originally to find out a clue for the nature of the plasma turbulence which is responsible for the energy dissipation. However the high frequency ($f > f_g^-$) part of the broadband electrostatic noise which is found to intensify during intervals of fast tailward flows cannot be identified as one of the normal modes of the electrostatic waves because of difference in the spectral characteristics. The absence of dispersion also suggests that the noise has not propagated from the source to the observing site as an electrostatic wave. Hence it seems rather likely that the broadband electrostatic noise represents an impulsive noise that is generated in the close neighbourhood of the probe.

Although the analysis of Gurnett et al. (1976) and of this paper could not identify the condition that is uniquely associated with the occurrence of the broadband electrostatic noise, the common denominator seems to be rapid changes in the field and particle environment in which the spacecraft is embedded. These changes include increases in the flow velocity, changes in density, and encounters with the trapping boundary

noted by Gurnett and Frank (1977). The noise however is not confined to the interval or region in which the changes take place but occupies a wider region surrounding or following the change.

If the noise is due to potential fine structures fixed to plasma and transported with it, the high frequency limit is set by the Debye length and the flow velocity. Since the flow velocity in the magnetotail usually has substantial component parallel to the magnetic field, the minimum scale length of the potential fine structure that traverses the spacecraft would be given by the Debye length λ . The observed parameters give $\lambda \sim 1$ km and the flow speed is mostly less than 1000 km/s, so that the time scale of the impulse to be observed by the spacecraft is longer than 1×10^{-3} s. Hence the potential fine structure can only give rise to frequency components below ~ 1 kHz while the broadband electrostatic noise extends to several kHz or sometimes to a few hundred kHz.

The nature of the noise appears to be either quasi-thermal noise in plasma or artificially generated disturbance arising from interactions of the spacecraft with the medium. This means that in the high frequency part at least the broadband electrostatic noise is probably a byproduct of the plasma condition created by the reconnection rather than being a constituent of plasma turbulence whereby energy is converted.

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Figure Captions

1. Velocity of the plasma flow in the ecliptic plane (top panel in each row) and inclination angle the magnetic field in the solar magnetospheric coordinates (bottom panel in each row). Small circles on the plots of the field inclination show the times of crossings of the neutral sheet. Thick downward arrows indicate onsets of fast tailward flows.
2. Strength of electric field (left) and magnetic field (right) at 16 frequency channels. Arrows correspond to those in Figure 1 and mark the onsets of fast tailward flows. The solid curve is f_g^- .
3. High-resolution frequency-time spectrograms (in negative) of the broadband electrostatic noise. (Intensity enhancement with a period of about 3.5s is an artifact produced by telemetry noise.)
4. Counts of energetic electrons observed by the GM counter (top), density of plasma (middle), and the electric noise strength at 1 kHz (bottom). Arrows above the middle panel corresponds to those of Figures 1 and 2.
5. Similar to Figure 4 but count rates of the solid-state telescope in the energy range of 47 to 350 keV are also shown.

6. Count rates of energetic electrons (top), electric noise strength at 1 kHz, and pitch angle distribution of energetic electrons at the three intervals indicated in the top panel.

7. Broadband electrostatic noise observed in a very quiet interval. Shown from the top are flow velocity vectors, plasma frequency, electron temperature, and electric field intensities at 16 frequency channels. Observation time (UT), radial distance, local time, and magnetic latitude of the satellite, and the AE index are indicated at the bottom.

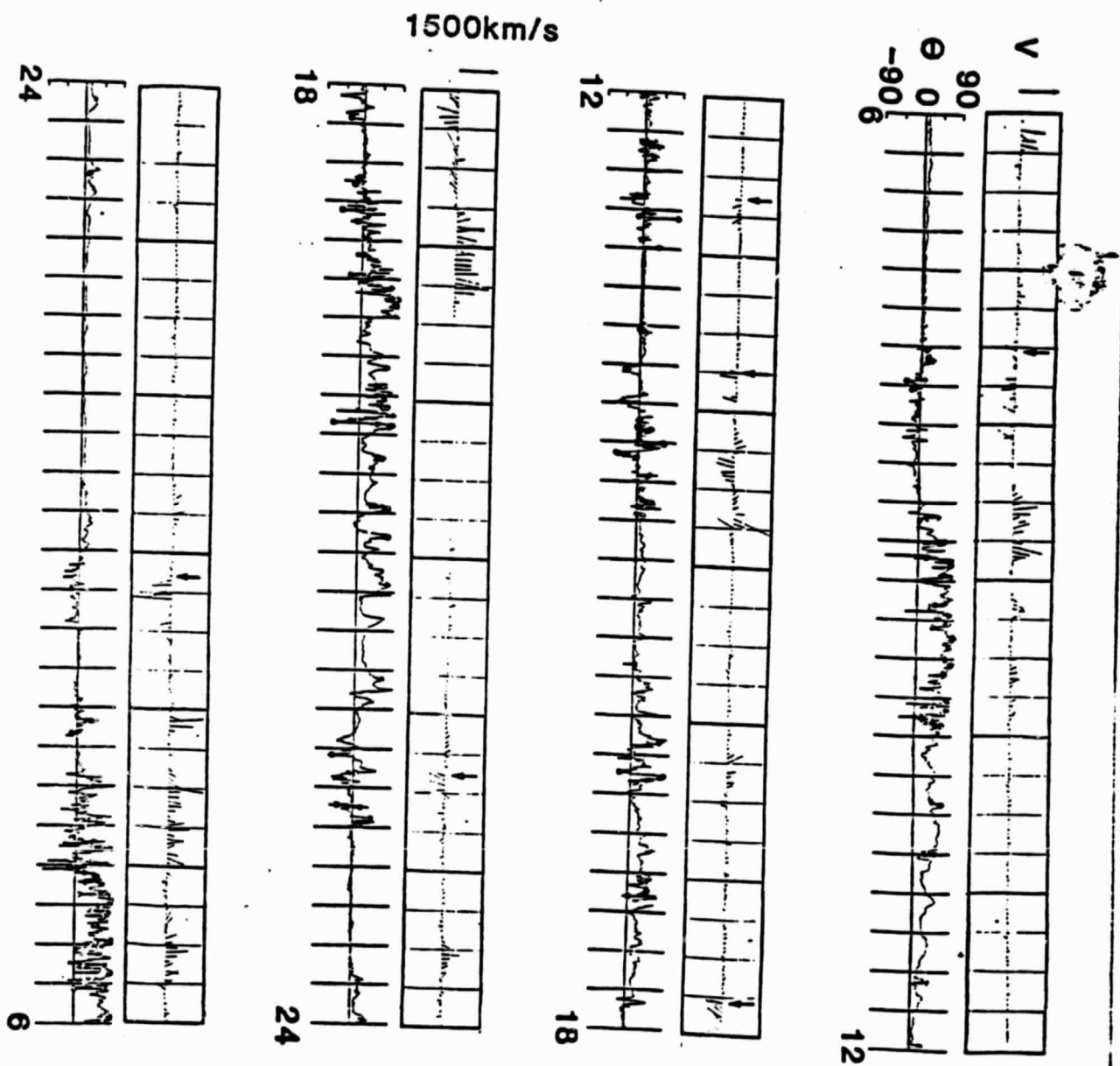
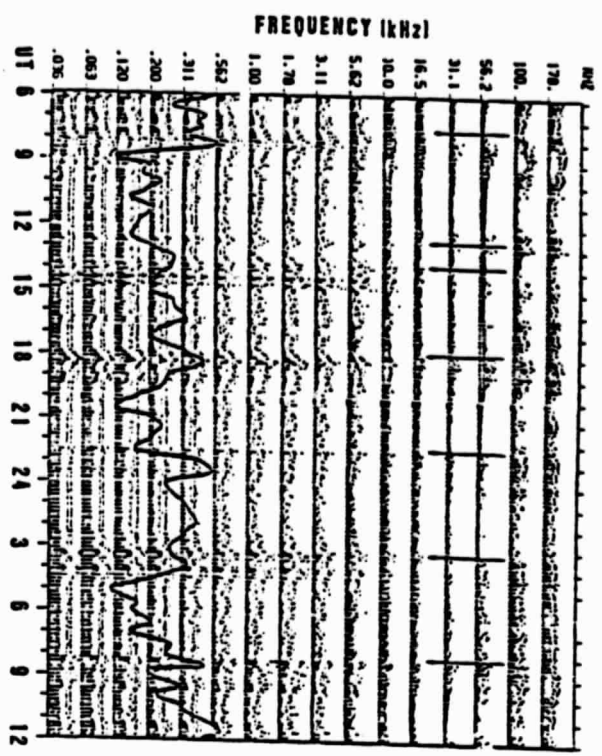


Figure 1

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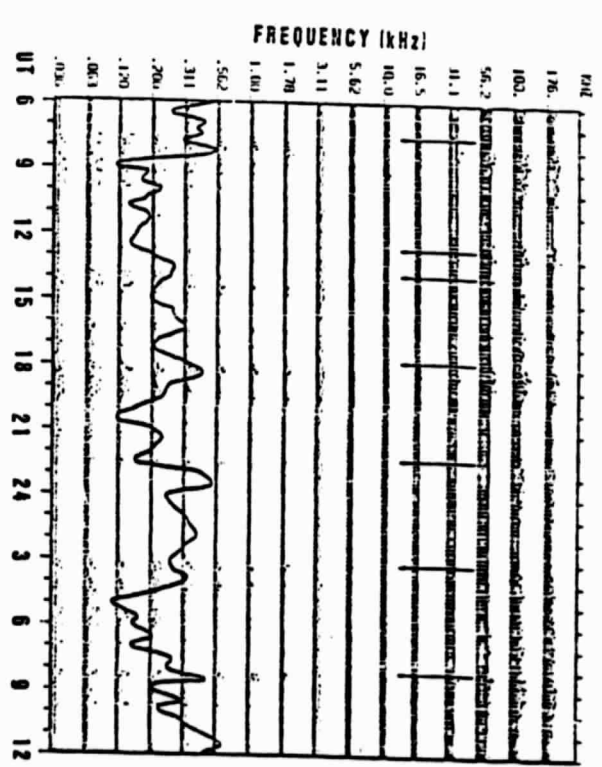
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ELECTRIC FIELD STRENGTH



October 20-21 1972

MAGNETIC FIELD STRENGTH



October 20-21 1972

Figure 2



OCTOBER 20 1972

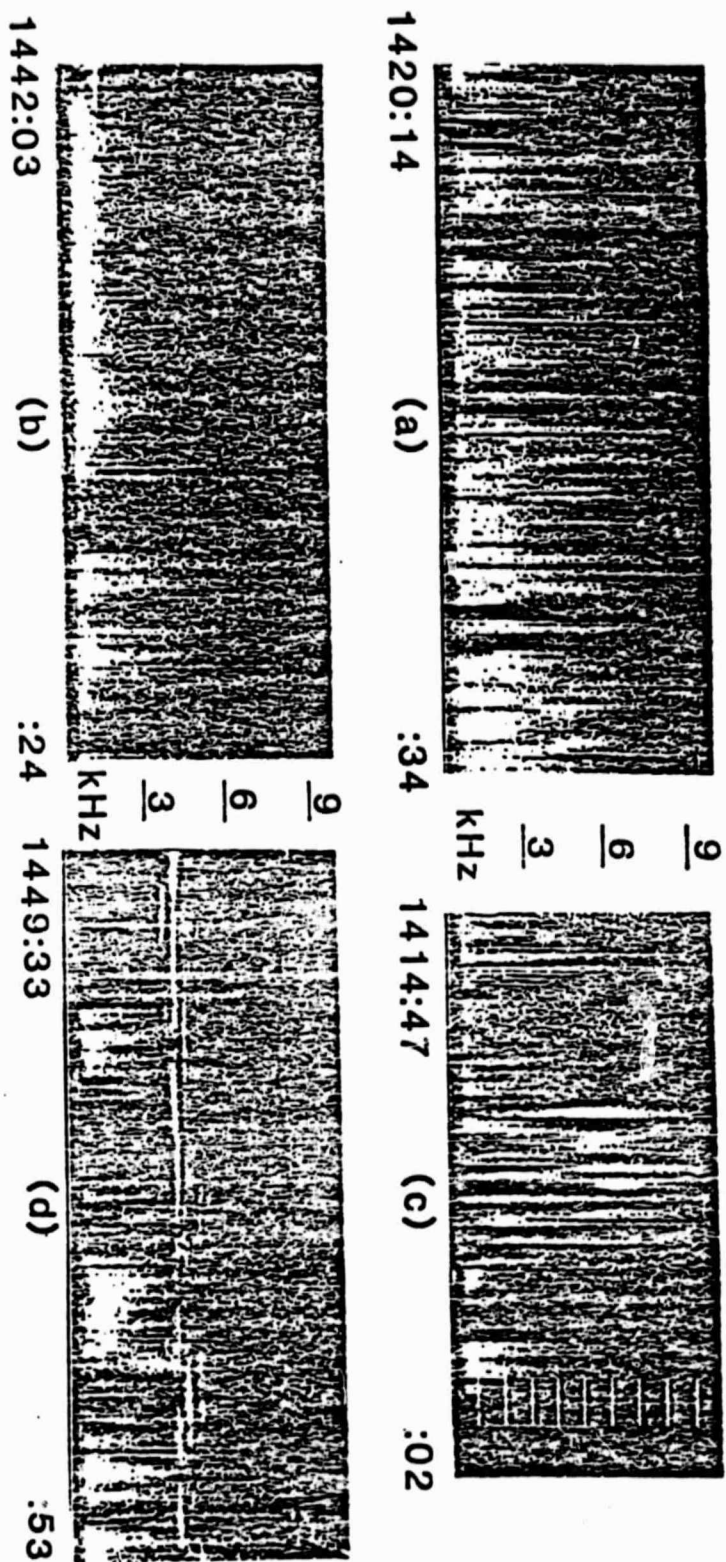


Figure 3

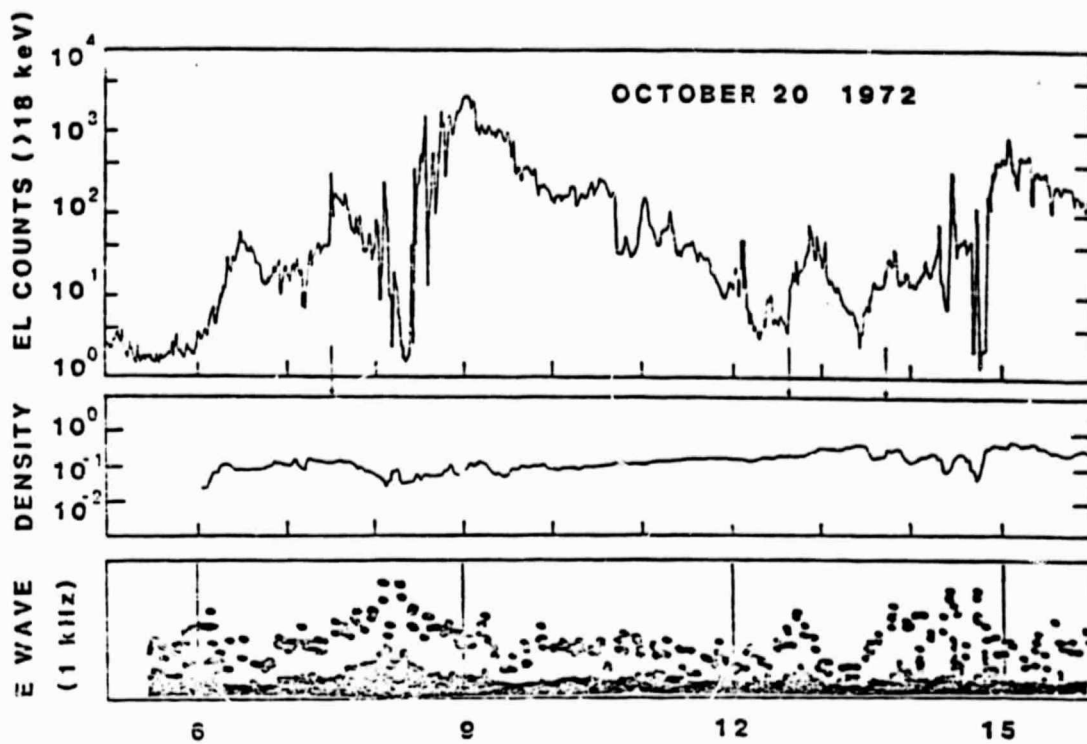


Figure 4

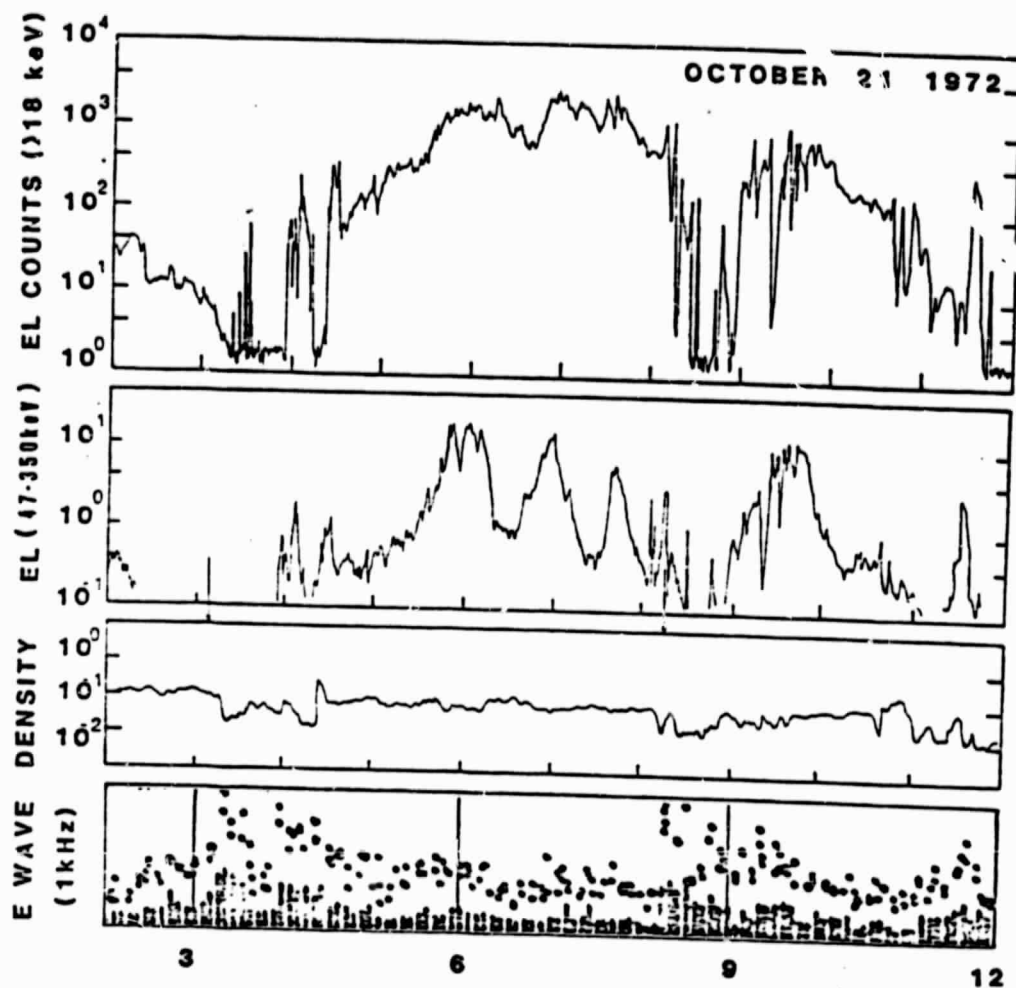


Figure 5

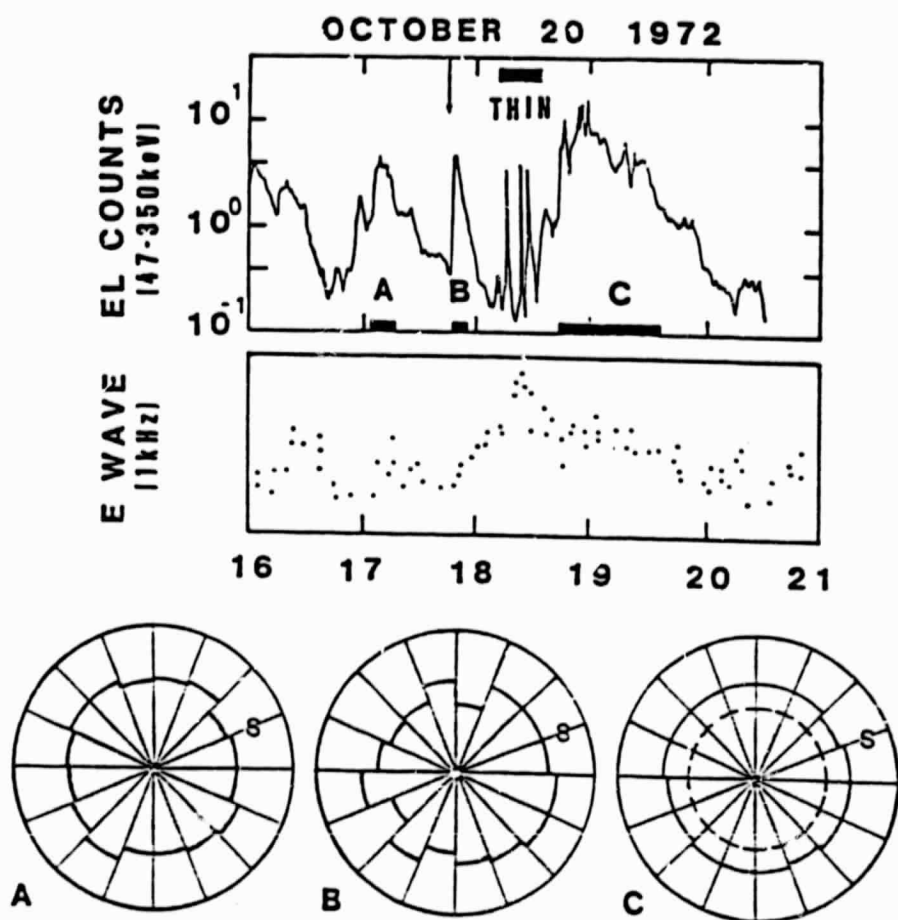


Figure 6